Galaxy Evolution Explorer
PI-mode Implementation Experience

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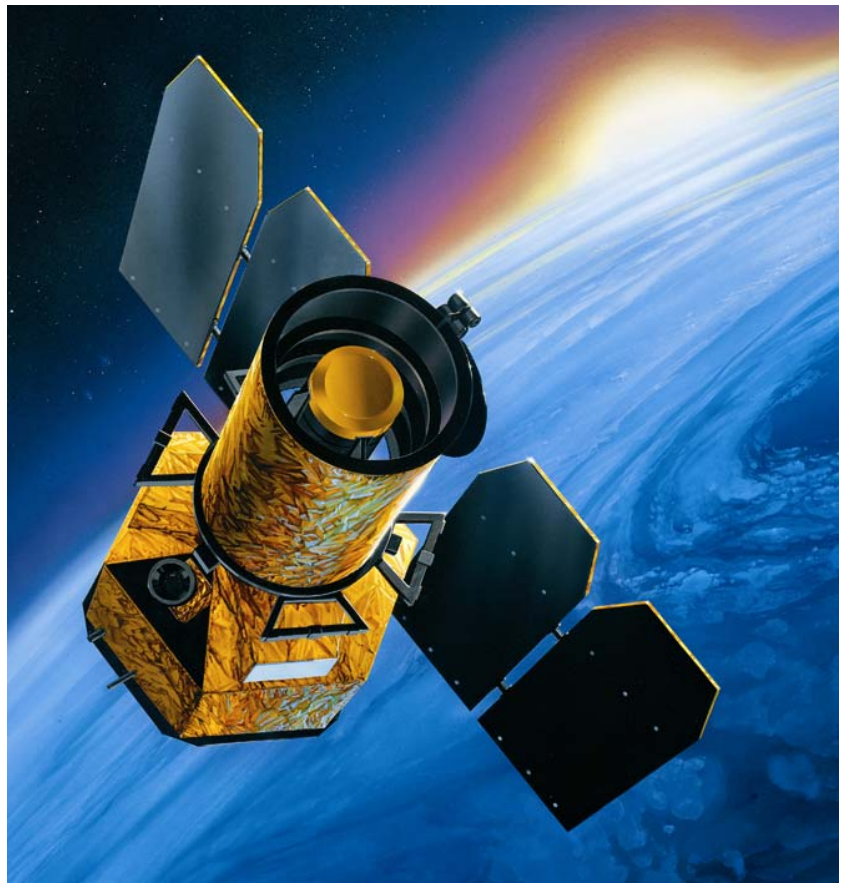
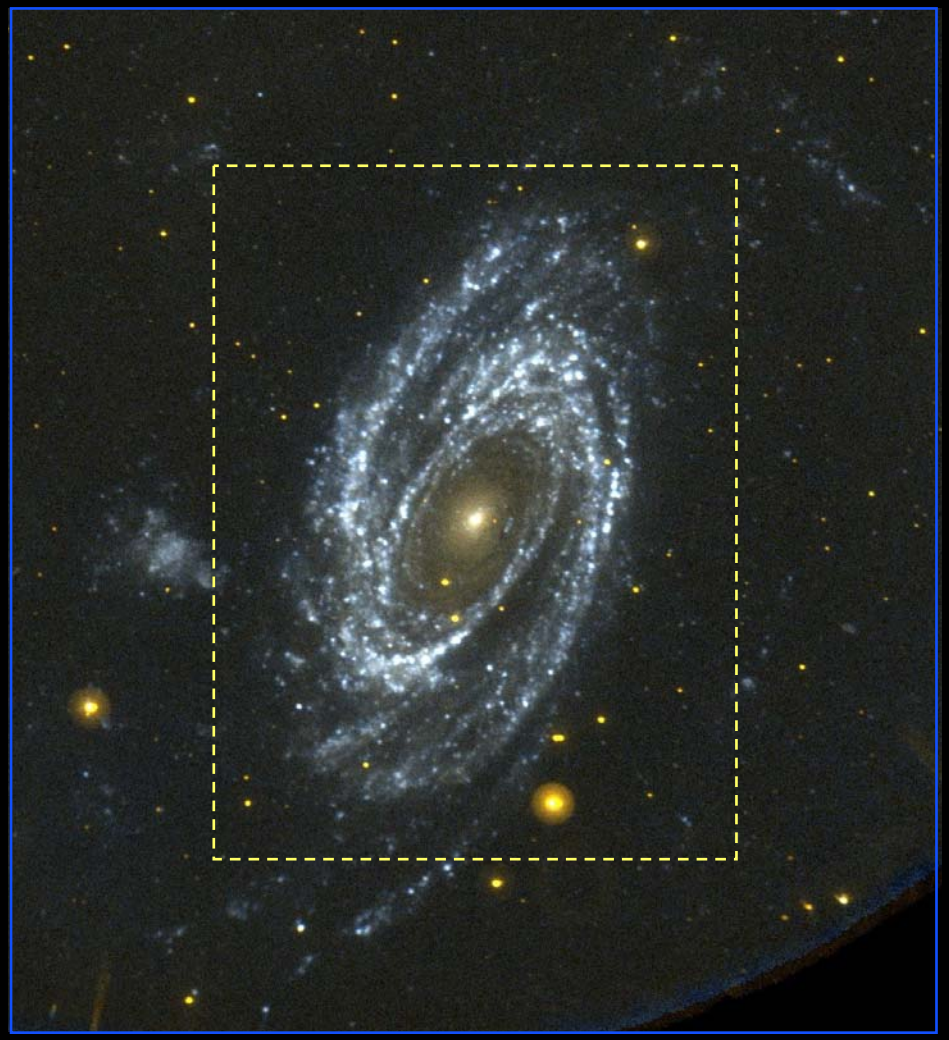
Mission Background

- Galaxy Evolution Explorer is a space telescope performing the first wide-area ultraviolet imaging and spectroscopic surveys of the heavens
- Primary mission is to map the history of star formation over 80% of the age of the Universe
- Wide range of secondary science, including large legacy data set, and discovery of new objects for follow-up by other observatories
- Small Explorer mission selected via AO 97-OSS-03
- Launched March 28, 2003
- Development cost: $72M



Science Quality Is Outstanding (M81 Galaxy Comparison, UV & IR)



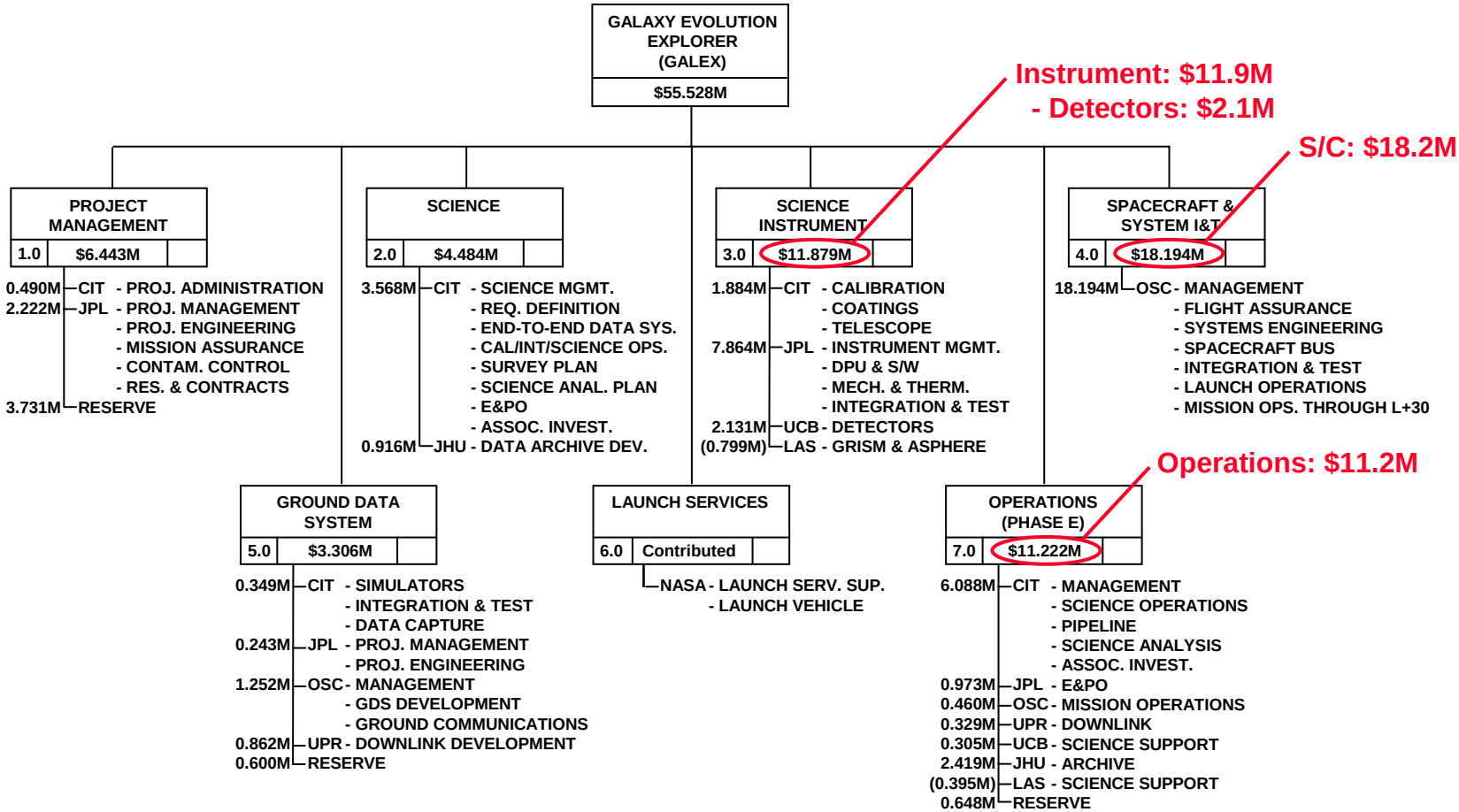
Ultraviolet
GALEX

Infrared
Spitzer

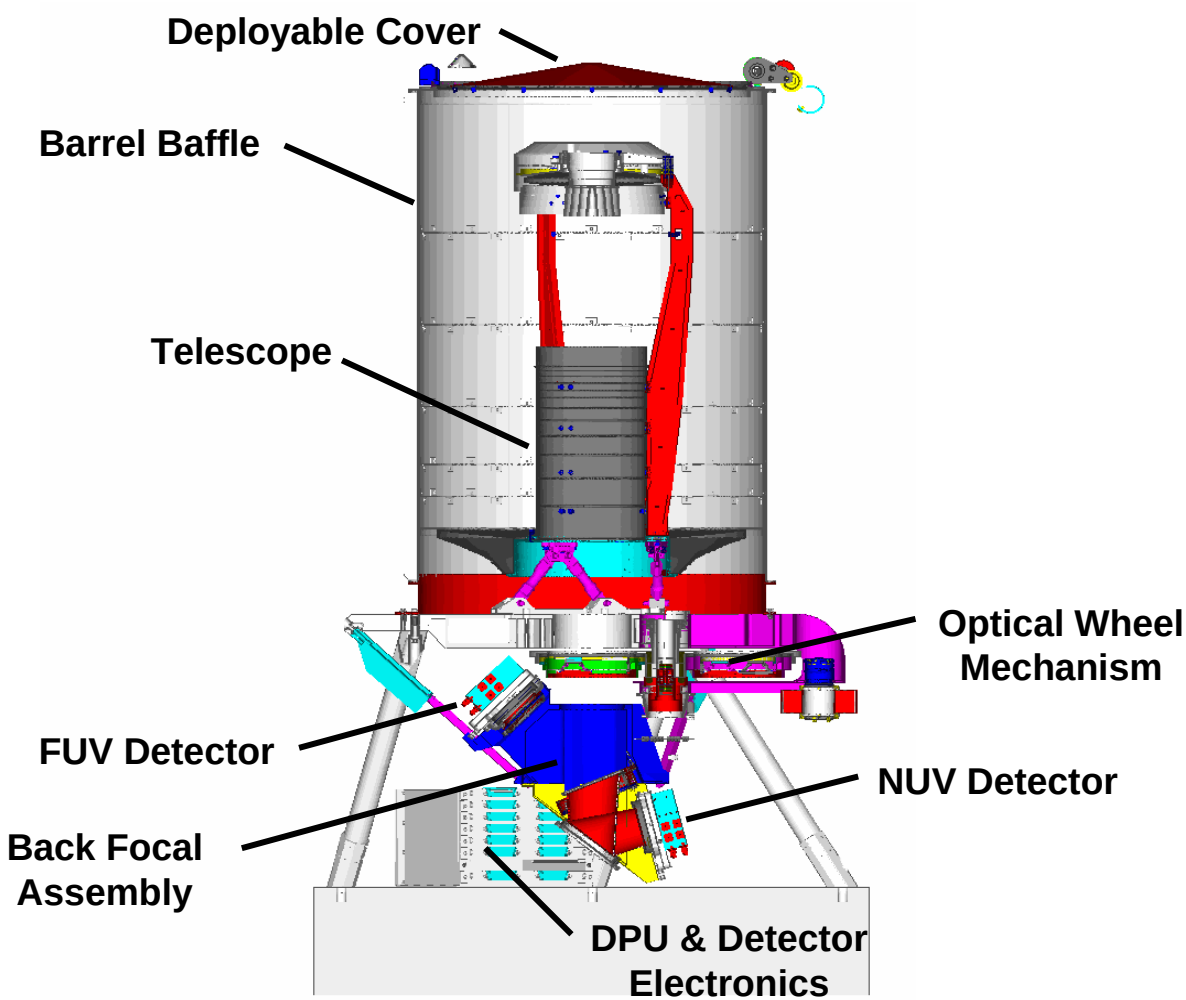
Mission Selection & Confirmation

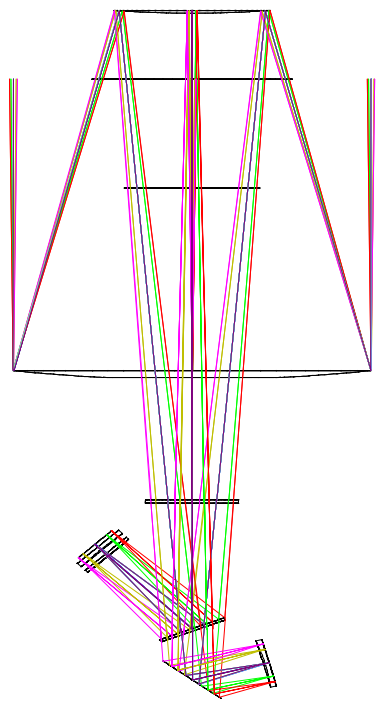
- Selection was essentially one-step, with “primary” and “backup” missions selected (GALEX was a “primary” mission)
  - *Step 1 proposal contained minimal requirements for management, cost, or schedule information; emphasis on science return*
  - *Lack of Step 2 down-select afforded NASA less opportunity to constrain implementation risk*
  - *Solicitation, selection, and confirmation all occurred during the period when the “faster-better-cheaper” paradigm was gaining momentum*
- Cost cap (all phases) $55.5M (RY$), including non-NASA contributions
  - *Implementation (B/C/D) phase proposed at $44.5M, phase E at $11M*
  - *Reserves (all phases) proposed at (and later confirmed at) $5M (10%)*
  - *Including non-NASA contributions against the cost cap affected ability to utilize ground data system assets of GALEX international partners (French and Koreans) that might have lowered cost risk*

Phase A
Costed Work Breakdown Structure



Instrument Configuration





Optical Ray Trace

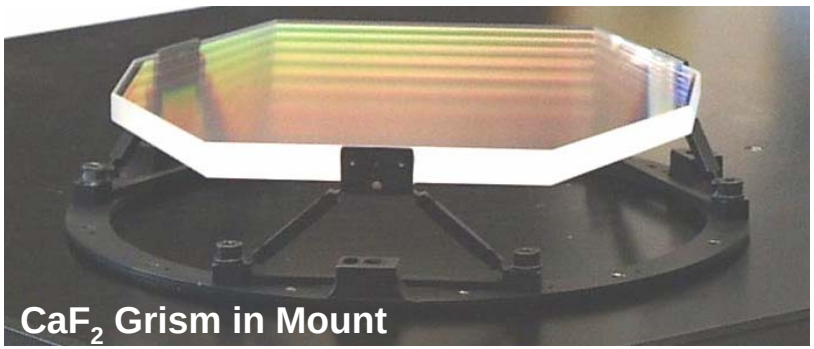
Instrument Equipment List

- 50 cm UV Telescope (Modified Ritchey Chretien)
- CaF_2 Grism (difficult technology) & Imaging Window
- Aspheric Beamsplitter (difficult technology)
  - *Unique Dichroic Multi-layer Coating (difficult technology)*
- Fold Mirror w/ Multi-layer Dichroic Red Blocking Filter
- Blue Edge Filter (Multi-layer Dichroic)
- 65mm dia NUV & FUV Sealed-Tube Photon-Counting Detectors (difficult technology)
  - *High Voltage Micro-Channel Plates*
- Detector Front End Electronics Unit (FEE)
  - *novel picosecond timing discrimination logic*
- Detector High Voltage Power Supplies
- Deployable Cover
  - *Wax Thermal Actuator Latch, Spring Hinge*
- 3-Position Optics Wheel (OW) Mechanism
  - *Mini Dual Drive Actuator Prime Mover*
- Grism Rotator Mechanism Riding on OW Mech.
  - *Stepper Motor Prime Mover w/ Optical Encoder*
- Digital Processing Unit (Rad6000)
- Single String Architecture

Instrument Components

Telescope Assembly

NUV Sealed Tube Detector

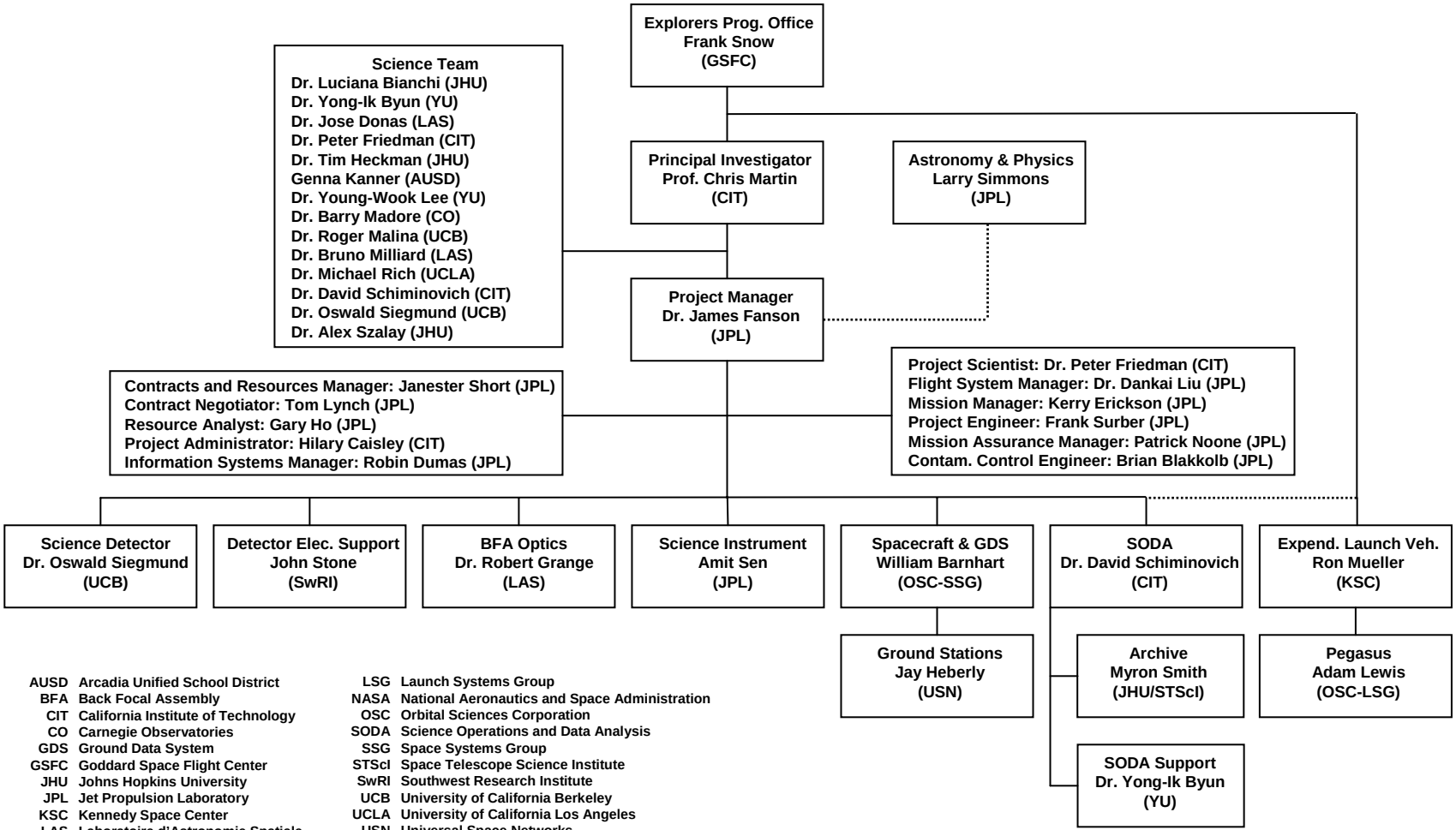

CaF_2 Grism in Mount

NUV Detector Window

Spacecraft Bus Equipment List

- 3-Axis Stabilized, No Consumables
- Central Electronics Unit (Rad6000)
- Power Regulation Electronics
- Attitude and Power Electronics
- Solar Panels (4) w/ Techstar Triple Junction Cells
  - *Wax Thermal Actuator Deployment*
- SIL S-Band Receivers (2) w/TDRSS Low Rate Link
- SIL S-Band Transmitter w/TDRSS Low Rate Link
- L3Com X-Band Transmitter 50 Mbps Downlink
- S-band antennas (2) & X-Band Antennas (2)
- 24 Gbit Seakr Solid State Recorder
  - *~32 Gbit Science Data per Day*
- Eagle Picher 16 A-hr Nickel Hydrogen Battery
- Ball CT633 Star Tracker
- Ithaco Type-A Reaction Wheels (4)
- Litton SIRU & Allied Signal RGA20 3-Axis IRUs
- 3-Axis Magnetometer
- Magnetic Torque Bars (3) and Torque Coil
- Coarse Sun Sensors (8)
- Single String Architecture

Implementation Project Organization



AUSD	Arcadia Unified School District
BFA	Back Focal Assembly
CIT	California Institute of Technology
CO	Carnegie Observatories
GDS	Ground Data System
GSFC	Goddard Space Flight Center
JHU	Johns Hopkins University
JPL	Jet Propulsion Laboratory
KSC	Kennedy Space Center
LAS	Laboratoire d'Astronomie Spatiale
LSG	Launch Systems Group
NASA	National Aeronautics and Space Administration
OSC	Orbital Sciences Corporation
SODA	Science Operations and Data Analysis
SSG	Space Systems Group
STScI	Space Telescope Science Institute
SwRI	Southwest Research Institute
UCB	University of California Berkeley
UCLA	University of California Los Angeles
USN	Universal Space Networks
YU	Yonsei University

Low Cost Implementation Approach

- JPL "University Mode" implementation was attempted
  - *Contract with Caltech Campus rather than JPL Prime Contract*
  - *Project Office established at Campus, collocated with PI and his team*
  - *Procurements via Campus overhead structure (including S/C)*
  - *Tailoring of JPL practices for low cost implementation*
  - *Scientists integrally involved with engineering and test (PI w/ risk mgmt.)*
  - *Risk acceptance*
- Procurement of Spacecraft "second of a kind"
  - *"First" copy to be developed by Orbital at least one year in advance of GALEX schedule; GALEX priced at "recurring cost" for bus*
- Ground Network Universal Space Network
  - *Venture capital start-up company, but lowest cost of very few options for low inclination orbit, X-band capability*
- Detectors from Dr. Ossie Siegmund (UCB, Space Sciences Lab.)
  - *The acknowledged expert for this detector type (& only remaining source)*

Contributions to Cost Growth

- Proposal Process
- Implementation Environment
- Risk (and Luck)

Contributions to Cost Growth Proposal Process

- Astrophysics "low hanging fruit" has been picked; scientific progress is getting tougher and requires very capable vehicles ⇒ technology
  - *PI's must pack more capability per dollar into proposals unless AO cost caps are raised significantly over time*
- PI's are motivated to propose in Step 1 at or near the cap in order to pack in as much science as possible for Step 1 (science) competition
  - *But, very little is known in Step 1 about the actual implementation cost*
  - *Small missions, like SMEX, are typically single-instrument, single-string, so there is little or no descope space actually available*
  - *"Minimum mission" definition usually isn't descope space so much as future cost risk mitigation (and probably not much of that)*

⇒ PI's get "squeezed" between Step 1 science commitment and AO cost cap before having a realistic idea of implementation cost
  - *Translates into very tight squeeze in Phase A (Step2), which promotes risk taking at the onset (at Step 2 the realistic cost is still not known)*

Contributions to Cost Growth Implementation Environment

- NASA's PI-mode acquisition model is essentially "fixed price" for a "one-off" product, without the PI being able to propose the cost reserve appropriate to a fixed price bid
  - *Realistic cost reserve would not compete in Step 1 (for GALEX, a fixed-price bid from the Spacecraft contractor would have consumed nearly all of the project reserve)*
  - *In actuality, implementation contracts are cost reimbursable, best effort; so there is, at least at some level, a structural inconsistency*
- A low-cost, fixed-price implementation approach needs a stable implementation environment to succeed (but is this realistic?)
  - *Changes in JPL implementation "rules," overhead rates, financial accounting system, ISO9000 certification, etc, are GALEX era examples*
  - *Changes in NASA requirements, and changes in enforcement of existing requirements (e.g. NEPA, ITAR, IT security, etc) are always occuring*
  - *The threshold of "acceptable risk" is an ever swinging pendulum*
    - It drops from Phase A to Phase D, and after any mission failure

Contributions to Cost Growth Risk (and Luck)

- Good management (including risk management) is not in itself a safeguard against cost growth
  - *Risk accepted at the beginning is very difficult (and costly) to buy down later (approaching launch, risk acceptance is guaranteed to be lower)*
- The more risk accepted at the beginning, the more susceptible the implementation is to "bad luck"
  - *Lack of spares, lowest bidders, and difficult technologies can over constrain the implementation and increase the "unknown unknowns"*
  - *Margins, including time and dollars, are needed to deal with the unexpected, especially when the implementation plan is aggressive*
    - Technologies <u>must</u> be ready before Phase C/D start (often not enough time to sufficiently retire risks on PI-mode schedules)
- "Bolts from the blue" still happen
  - *Companies fold, environmental test equipment fails, "good" parts and components suddenly become "bad," export control regulations can lead to "logic-free zones," etc…*

PI-mode Missions Provide NASA with Excellent Value

- Missions are focused, and PI's are highly motivated to provide best possible science
- Attempt to meet cost caps generally produces incredible effort by implementation teams (significant uncosted labor)
- Value (science per dollar) is high, even if cost caps are exceeded
- Overall, the PI-mode actually serves NASA very well, but could be improved
  - *Increased emphasis on cost risk early in selection process*
  - *Some method for permitting adequate reserves, while remaining scientifically competitive (if NASA really wants to pursue a "fixed price" acquisition model on "one-off" developments)*
  - *Agreement up front on "acceptable" risk, and stability throughout the development*
  - *NASA HQ and Center roles, requirements, and standards must remain stable throughout the development*